AN INTEGRATED SYSTEMS APPROACH TO HUMAN FACTORS IN COMMERCIAL AVIATION MAINTENANCE SYSTEMS

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Introduction

The application of human factors concepts to commercial aviation maintenance has been directed primarily to issues involved with operational and personnel safety. Building on the success the crew recourse management (CRM) concept, human factors training for maintenance technicians and inspectors has gained industry acceptance and regulatory support. For example, the Joint Aviation Authorities (JAA) of Europe and Transport Canada have set requirements for maintenance human factors training (1, 2). More recently, human factors concepts have been applied to maintenance error investigation, again focusing on the maintenance technician and inspector. Tools for investigating errors made by technicians and inspectors, such as the Boeing Maintenance Error Decision Aid (MEDA) (3), have helped identify factors that contribute to error, such as fatigue, shift hand-over procedures, organizational support, and confusing or misleading information in maintenance documentation. There is also an increasing regulatory movement towards requiring the use of human factors concepts in the day-to-day operations of a maintenance organization. The JAA has published Notice of Proposed Amendment 145-12, which could eventually require maintenance organizations to apply human factors concepts to issues such as procedural non-compliance, shift and task hand-over, fatigue, and poor task planning. The focus of proposed rule is the reduction of error and the promotion of maintenance and personnel safety.

Current economic conditions have emphasized the need for human factors in all aspects of commercial aviation maintenance operations. Increasing requirements to do more with less, as well as the projected shortage of trained and experience maintenance personnel, have placed additional pressure on airline management to employ their workforce more efficiently. Airline management needs help and human factors can provide it. Human factors processes can provide management with powerful tools for determining the appropriate levels of training, information and material requirements that their workforce needs to effectively do their job. Not only does this lead to a more efficient workforce but a more efficient allocation of the maintenance organization's resources. Other human factors concepts, such as those regarding organizational structures, policies, and procedures, are central to the development of a maintenance organization that employs its workforce in the most cost effective way. The implementation of a human factors program therefore provides a significant economic advantage to a maintenance organization by both avoiding the costs associated with the results of human error and the direct reduction of costs resulting from increased workforce efficiency.

This paper describes an integrated systems approach to the application of human factors processes in commercial maintenance operations. The basic approach has been successfully applied to the development of a number of large complex systems, such as ground based maintenance system for the C-17, ballistic missile basing systems, and numerous command, control and communications systems. The approach will assist a maintenance organization in clearly defining maintenance system requirements not only in terms of safety and airworthiness but also profitability. Second, it provides a framework for requirements traceability to assure that all system requirements are addressed. Finally the approach uses a common set of human factors tools and processes that can be applied to all human activity throughout the maintenance system. This provides a very cost effective way to develop and maintain a human factors program that is applicable to all aspects of the maintenance operation.

Human factors in the commercial aviation maintenance system

A modern commercial aviation maintenance operation is a complex sociotechnical system developed to ensure the availability of safe and airworthy aircraft at the lowest cost. The system is composed of equipment, facilities, tools, software and people, all interacting to produce the system's products. Human factors is concerned with the human component of the system, the performance of the workforce, and the effect other system components have on the human's ability to do his/her job. It is at these human-system interfaces, such as equipment controls and displays, computing system interfaces and tool designs, that human factors applies its knowledge of human capabilities and limitations to insure that human performance is optimized. To be successful, however, the maintenance system must not only optimize the interface between the human component and the rest of the system, but also utilize human capabilities in the most productive manner. It is not enough just to assure that the functions and tasks allocated to humans are consistent with their capabilities and limitations, they also must be appropriate in terms of both the individual and the system (4). This requires that human factors concepts and processes be applied at both the level of the individual worker and at the system level in terms of organizational design, policies and procedures.

Human factors program elements

The integrated systems approach to human factors in maintenance systems is designed to provide a maintenance organization with a human factors program structure that will allow the maintenance organization to address a wide range of human factors issues within the maintenance operation. The approach is structured around three human factors program elements:

- Error risk management
- Ergonomic injury risk management
- Workforce performance optimization

Error risk management

Currently, the application of human factors principles to commercial aviation maintenance operations is primarily associated with error risk management. It has been well documented that human error is a significant factor in maintenance system performance. Maintenance and inspection errors have been involved in approximately 15% of all hull loss accidents and are the second leading cause of onboard fatalities. Events resulting from maintenance and inspection error, such as flight delays, cancellations, diversions and in-flight shutdowns, have significant economic impact on airline operations. Human error also plays a central role in other incidents resulting in aircraft and equipment damage as well as personal injury. Human factors based initiatives, such as maintenance resource management (MRM) and human factors awareness training, address issues relating to the identification and management of factors known to contribute to error. Error investigation tools, such as MEDA, are employed to identify those factors in the maintenance system that contributed to the error. In the integrated systems approach the error risk management program element combines both error investigations with a more proactive program of assessments and audits to identify conditions within the maintenance system that increase the possibility of error. These risk factors are then assessed both in terms of error probability and the potential outcome if the error should occur. By assessing both probability and outcome the maintenance organization can establish the relative significance of the error, that is, which potential error poses the most significant risk to the system and what is the most cost effective approach to managing it.

Ergonomic Risk management

In addition to the risk of injury resulting from accidents such as trips or falls, human factors is involved in the prevention of a class of musculoskeletal injuries that are the result of repeated microtraumas. These types of cumulative trauma disorders (CTD) such as tendonitis or carpal tunnel syndrome are commonly referred to as ergonomic injuries. Like acute injuries that are generally associated with human error, the probability of sustaining a CTD is increased as a result of the presence of certain risk factors in the work place. Not coincidentally, a significant number of ergonomic injury risk factors such as fatigue or highly repetitive tasks, have also been shown to increase error risk. Human factors processes have been effective in identifying and managing these ergonomic risk factors. As with error risk management, these risk factors undergo a further risk assessment to determine their relative significance and initial requirements for risk management.

Workforce performance optimization

Perhaps the least recognized area where human factors can contribute to the enhancement of maintenance operations is workforce performance and productivity. It has been estimated that approximately 55% of an average maintenance organization's annual budget is expended on workforce labor costs (5). This number represents a significant cost to the airline and offers a number of opportunities for increased efficiencies and cost

reductions. Human factors can provide the tools necessary to identify and manage those factors that have either a positive or negative effect on organizational, workforce and individual worker performance. Human factors participation in quality improvement activities, resulting from management initiatives or quality assessments, can insure that functions allocated to workers are consistent with their capabilities and limitations and that all human-system interface requirements are identified.

The integrated systems approach

The integrated systems approach combines human factors concepts with systems engineering principles to:

1. Develop clears meaningful maintenance system improvement objectives.
2. Provide a structured process to insure that any potential system improvement is consistent with all other maintenance system objectives.
3. Integrate all maintenance system improvement activities that involve human component issues through a common human factors tool set.

This approach to human factors can provides a maintenance operation with a low cost and effective mean ensuring its workforce is successfully integrated into the maintenance system. The approach is based on three principles:

- All system requirements are weighted equally and all must be met. No single requirement--aircraft availability, safety, airworthiness or cost--has priority in maintenance system operations; they all must be achieved equally. For example, a strategy designed to mitigate a contributing factor to maintenance error must not adversely affect aircraft availability or cost.

- Maintenance system improvements involving humans are measured in terms of system performance. For example, the effectiveness of an error management strategy must be measured in terms of increasing the availability of safe and available aircraft at the lowest cost, not reduced error rates. The use of human performance as the measure of effectiveness may very well result in a strategy developed strictly to reduces error rates at the expense of cost and aircraft availability. Ultimately the most effective solution at the system level might be to allow the error rates to remain the same but increase the error tolerance of the system.

- Human factors principles are applied to all levels of human activities within the maintenance system. As with any system, the performance of any component affects a number of other components or subsystem within the system. Sub-optimal performance, such as human error in one department like material or engineering, has been shown to contribute to errors committed by maintenance technicians in the shops or maintenance hangars. Those performance shaping factors that resulted in the original error must be addressed before the risk of the maintenance error can be effectively managed.

The basic system approach integrates the three human factors programs through a common set of human factors processes (See figure 1).

One major feature of the approach is a process for clearly defining the objectives for maintenance system improvements prior to any design activity. The objectives are defined not only in terms of the original issues such as mitigating a risk factor for

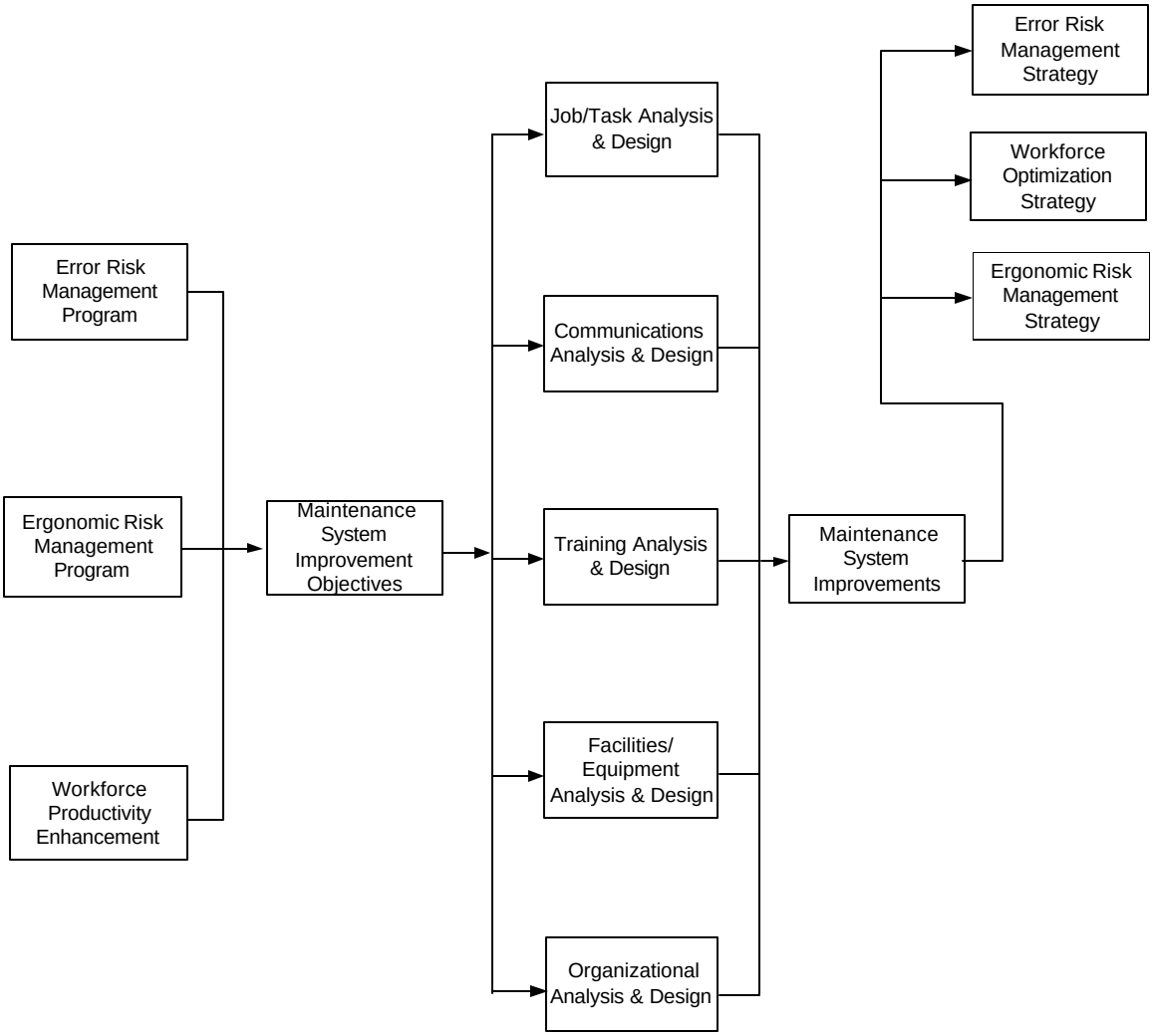

Figure 1. Integrated Systems Approach

error, but also to support over all maintenance system objectives. The integrated systems approach achieves this by applying systems performance criteria during the development of the improvement objectives, not the resulting design. The initial goals for the objectives are developed by the three program elements. The goals can range from the management of risk factors for errors or ergonomic injury to improvements in areas of less than optimal maintenance system performance such as production choke points. To insure that potential system improvements do not adversely affect other aspects of the

maintenance system, they are assessed to determine their compatibility with the general maintenance system requirements of safety, airworthiness, aircraft availability and cost. In addition to maintenance system requirements, the proposed objectives are assessed for their affect on error risk, ergonomic injury risk and human performance to insure that all human-system interface issues.

The development of the actual system improvements involves the use of standard human factors tools and processes. These tools and processes (human factors tool set) have general applicability throughout the entire human factors program including all program elements, and in fact act to integrate the program. The use of the human factors tools set therefore, provides a low cost way for a maintenance organization to establish and maintain human factors program that addresses all aspects of human performance in their operation. The common human factors tool set addresses five basic human factors competencies:

- Job/task analysis
- Facilities and equipment design
- Organizational issues and design
- Training
- Communications.

Job/task analysis and design. Job/task analysis (JTA) provides a detailed picture of how specific jobs and tasks are organized and sequenced, and how they affect worker performance (5). JTA also provides a method of identifying knowledge, skill, and ability requirements. It also can be used to identify job-related hazards. Specific aviation maintenance applications include maintenance error risk assessments, identification of training requirements, design of training programs, injury risk assessments and the identification of skill requirements for employment and placement.

Facilities and equipment design. The analysis and design of facilities and equipment, including tools, combine an understanding of human capabilities and limitations with the biomechanical principles of how people work. Specific maintenance applications include hand tool selection, support equipment selection and design, facility design and utilization planning, maintenance error management, and injury risk management.

Organizational issues and design. Organizational factors, such as organizational structures, policies, and procedures, have a significant effect on human performance. Human factors processes apply principles of industrial and organizational psychology, as well as industrial engineering, to ensure that the maintenance organization employs its workforce effectively and creates an environment that has a positive effect on individual worker performance. Examples of organizational issues specific to airline maintenance operations are policies for task and shift changeover, shift rotation, and discipline.

Training. Human factors processes for training development are based on a systems engineering approach. Training objectives are developed according to the knowledge, skills, and abilities required to perform certain tasks and jobs. This allows the maintenance organization to develop its own effective training and to assess the

applicability and effectiveness of commercial training products before purchasing them. Other applications of this approach include the development of structured on-the-job training programs and the mitigation of knowledge and skill deficiencies identified from accident and error investigations.

Communications. Maintenance organizations most commonly transfer information throughout their workforces using written communication, although verbal communication and nonverbal methods (such as hand and arm signals, warning signals, signs and zone markings) also are commonly employed. Human factors processes assess communications requirements based on the information needs of both the sender and receiver. Once information requirements are established, the best communications method can be determined. Currently, the principal application of these processes and in maintenance organizations is the assessment of communications systems as a possible source of maintenance errors.

The resulting maintenance system improvements may be developed to enhance a workers ability to do his job in a safe and efficient manner or increase overall workforce productivity. The improvements can range from things as simple as providing supplemental lighting to changes in policies, procedures or even organizational structures. Whatever the improvements are they must demonstrably increase the maintenance systems ability to assure the availability of safe and airworthy aircraft at the lowest cost to the organization.

Conclusion

In the past several years there has been an increasing recognition of human factors contribution to the enhancement of maintenance safety. Human factors awareness training and the application of MRM concepts have gained industry wide acceptance as well as the use of error investigation techniques such as MEDA. Human factors has however, much more to offer to a maintenance organization both in the areas of safety and profitability. The same concepts that human factors professionals employs to identify and manage the factors that have been shown to contribute to human error and accidents can be effectively used to increased the productivity of the maintenance organizations workforce. The integrated systems approach to human factors offers the maintenance organization a cost effective means of applying human factors principles to the entire operation through a process of requirements integration and through the application of a common set of human factors tools and processes.

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